A comparison of mechanically ruled versus holographic varied line spacing gratings for a soft X-ray flat field spectrograph

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INTRODUCTION

Soft X-ray flat field grazing spectrographs are widely applied for plasma diagnostics[1]. These spectrographs take advantage of the recent significant progress of 2-D detectors. In 1982, Fonck et al[2] developed a near grazing-incidence (α = 70.6°) spectrograph which uses an aberration corrected holographic grating. The grating was recorded by a system consisting of two coherent point sources. This spectrograph has a quasi-flat focal curve and a flat focal field in the wavelength range of 10-17 nm. With the advent of the modern numerical-controlled ruling engine[3] it became possible to fabricate a wide variety of varied-line-spacing (VLS) gratings. Taking advantage of this, Nakano et al[4] developed a compact flat-field grazing incidence soft X-ray spectrograph working in the 0.5-40 nm region. In this spectrograph, the focal plane is almost perpendicular to the diffracted rays, an advantage for the use of 2-D detectors.

Recently laminar-type holographic gratings have been revived in the soft X-ray region. The advantages of laminar-type holographic gratings over mechanically ruled gratings are: 1) the suppression of overlapping higher orders; 2) reduced scattered or stray-light[5,6]; 3) durability to higher heat loads.[7] The purpose of this note is to present measurements of the diffraction efficiency and resolution of a laminar-type holographic grating recorded by aspheric wave-fronts[8] and a blazed-type aberration corrected ruled grating.

SPECTROGRAPH AND GRATING DESIGN

A schematic diagram of the soft X-ray flat field spectrograph[4] is shown in Fig.1. A spherical holographic grating G accepts light emerging through an entrance slit E. Diffracted light is focused on an image plane Σ that makes an angle ϕ with the plane Σ_0 that is perpendicular to the diffracted principal ray OB_0. The angle ϕ is positive when measured counterclockwise from Σ_0 toward Σ and $|\phi| \leq \pi/2$. The basic design parameters are as follows.

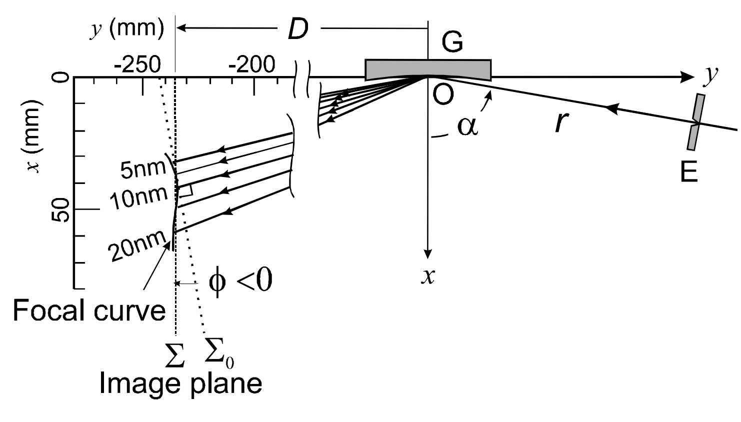

Figure 1. Schematic diagram of the soft X-ray flat field spectrograph.

The radius of curvature of the grating R = 5606 mm; effective grating constant σ = 1/ 1200 mm; ruled width W = 50 mm; ruled height L = 30 mm; slit height H = 1 mm; wavelength of the recording laser λ_0 = 441.6nm; spectral order m = +1; distance from slit to the grating center, r = 237.0 mm; incidence angle α = 87.0°; distance from the focal plane perpendicular to the y-

axis to the grating center D = - 235 mm; and wavelength range of a 5-20 nm. Therefore, the distance from grating center to the image plane $r' = 235/\cos(\pi/2 + \beta_0)$, and $\phi = -\beta_0 - \pi/2$.

We used an aspheric wave-front resulting from the reflection of a spherical wave-front from a spherical mirror to record a holographic grating. The design parameters were determined by the analytical design method[9] are given below: r_C = 1890.99 mm, R_2 = 570.00 mm, p_D = 546.13 mm, q_C = 498.60 mm, γ =–60.0002°, δ = -19.6399°, η_D = 50.1400° . λ_0 = 441.6nm. For the definition of the parameters refer to Ref. 8. The substrate of the holographic grating was SiO_2 with a RMS roughness of 1 nm. The photoresist, OFPR5000, was used as an etching mask. The sinusoidal grooves of the holographic grating thus recorded were processed into laminar grooves by reactive ion beam etching in CHF_3. The groove depth of 10 nm and the groove width to groove spacing ratio of 0.34 were etched on the blank. After making the grooves the surface was coated with Au of a 100 nm thickness.

As a reference, we also measured a blazed-type mechanically ruled VLS grating[3]. The radius of curvature R and groove parameters n_{20}, n_{30}, and n_{40} for this grating are: R=5649 mm, $n_{20} = -7.08090 \times 10^{-3}$mm^{-1}, $n_{30} = 2.85666 \times 10^{-5}$mm^{-2}, $n_{40} = -5.25446 \times 10^{-7}$mm^{-3}. The blaze angle is 3.2° and the coating material is Au. The blaze wavelength at the incidence angle α = 87° is 10 nm.

EXPERIMENT

The absolute efficiency of both the holographic and the ruled VLS gratings were measured at the standards and calibrations beamline 6.3.2, built and operated by Center for X-ray Optics at the Advanced Light Source (ALS), Lawrence Berkeley National Laboratory. The measurements were performed at a fixed incident angle α=87° just as the gratings are used in the spectrograph. The results are shown in Fig. 2 for spectral orders $m=0,1,2$. For the m = +1 order, as expected, the ruled grating has a higher efficiency than the holographic grating except for wavelengths shorter than 6.5nm. An essential difference can be seen in the higher orders, between the two gratings. For the holographic grating, the ratio of the second order to the first order efficiency is about 10% and is independent of wavelength. Whereas for the ruled grating, the second order to first order ratio varies from ~300% at 4.5nm to ~10% at 20nm. The cross point of the efficiency curves for the first and second order lights is 6.5 nm, and below this wavelength the second order is stronger than the first order.

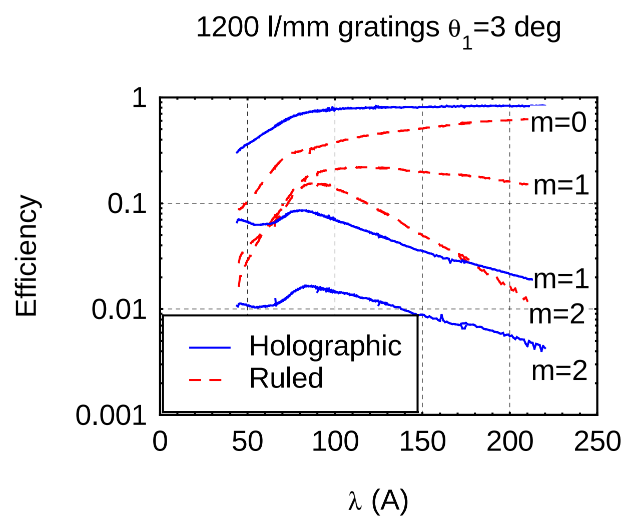

Figure 2. Efficiency measurements for the holographic and mechanically ruled gratings versus wavelength.

A measurement of the spectral resolution was performed using a spectrograph with a laboratory X-ray source at Research Institute for Scientific Measurements at Tohoku University. This system consists of the soft X-ray generator (The Manson model 2 mini-focus ultra-soft X-ray source), a vacuum spectrograph having the correct mounting parameters assumed at design stage of the gratings, and a microchannel plate with a 1-D photodiode array as a focal plane detector (Hamamatsu Photonics C2321-01). The emission band of C-K (4.4 nm) generated at a power of 4kV and 0.035mA was observed for a 10 min. exposure time (refer to Fig.3). The intensity was normalized to the intensity of the first diffraction order. For the ruled grating, relative intensity of the second (or third) order light to the first order light is about 95% (or 80%), and up to sixth order is observed. On the other hand, for the holographic grating the relative intensity of the second (or third) order is less than 10% (or 5%). This result also confirms the character of extremely lower higher order lights of the holographic grating than the ruled grating.

The FWHM of the first order is about three times worse (4 A) for holographic grating as compared to (1.5 A) the ruled grating. In addition, the dispersion of the holographic grating is slightly smaller than that of the ruled grating. It is likely that these are the result of alignment errors in the recording system of the holographic grating. Actually, for a small change of the incident beam direction, the best image point of the first order light was shifted. Therefore it is possible that a small correction of the recording system or an adjustment of the focal curve to the detector plane could improve the FWHM value for the holographic grating.

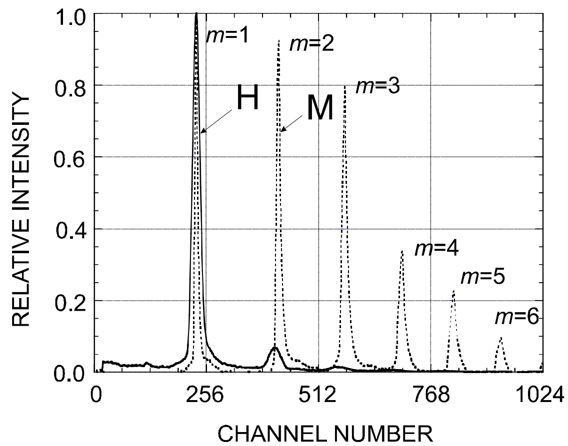

Figure 3. The normalized spectrum of 4.4 nm C-K band. The full and dotted lines show the intensity of the holographic grating and ruled grating, respectively.

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